Report as of FY2008 for 2008GU132B: "Using Remote Sensing to Determine Changes in Soil Erosion and Sediment Loads from Guam Badlands"

Publications

- Water Resources Research Institute Reports:
    - Khosrowpanah, Shahram; Maria Kottermair, 2009. Spatial Distribution of Badlands in Ugum Watershed: Characterization and Temporal Analysis, Water and Environmental Research Institute of the Western Pacific, University of Guam, UOG Station, Mangilao, Guam, Technical Report No. 126, 27 pp.

Report Follows

PROJECT SYNOPSIS REPORT

Project Title: Using Remote Sensing to Determine Changes in Soil Erosion and Sediment Loads from Guam Badlands

Problem and Research Objectives

Soil erosion creates several environmental problems for the island on Guam. Excessive soil loss degrades the quality of the topsoil and its ability to sustain agriculture. The detached sediment particles are transported by surface runoff to lower areas and eventually deposited into nearby rivers and other water bodies. The highly turbid water flowing into the ocean can damage the coral reef system, which are an important natural as well as economic resource for Guam.

In southern Guam, drastic soil erosion processes mark the savanna landscape in the form of large, orange-red colored erosion scars, so-called badlands. The countless red spots as visible apparent on satellite imagery are evidence for their vast existence throughout the southern watersheds. Badlands are continually eroding soils on steeply sloping terrain.

Previous studies (NRCS 1996, Scheman 2002, Khosrowpanah et al. 2007) have identified badlands as a primary source of sediment loads. Erosion control practices have the potential to minimize soil losses and to improve water quality. However, controlling soil erosion in watersheds in costly and time-intensive; therefore, it is critical to understand the behavior of badlands better before implementing watershed management practices.

The overall goal of this project was to; a) identify, map and analyze the changes in badland areas over time, b) characterize badlands in respect to topographic variables and their structural pattern. The specific goals were:

1. To compile an inventory of all available aerial images of Guam, including historical aerial photographs and recent satellite imagery, and select two suitable images for the badland change analysis.

2. To georeference the selected images in the geographic information system (GIS) software ArcEditor 9.1 and digitize the extent of badlands in both images. Further, to detect changes in badland cover over time via raster analysis.

3. To find a relationship of the current badland extent and topographic variables (elevation, slope, aspect, distance to drainage divide, geology, and soils) via frequency distribution to identify preferable conditions of badland formation using the GIS extension Spatial Analyst and Microsoft Excel.

4. To recommend appropriate soil erosion control practices and re-vegetation methods for the badlands.

Methodology:
Traditional field inventories and surveys may accurately delineate the boundaries of each badland area and associated terrain attributes, but it is very time-consuming and the areas are often hard to access. In addition, the extent of badlands has not been monitored in the field in the past and, therefore, makes a long-term badland change analysis using field data impossible. New technology such as remote sensing and geographic information systems (GIS) can overcome these challenges. Currently, Guam has several aerial coverages taken in different years, dating back to 1946. Earlier coverages were captured from airplanes on black-and-white film, while more recent multi-band images were acquired from satellites such as Landsat, IKONOS, and QUICKBIRD. Two images, a historical aerial photo and a current satellite image, were utilized to analyze the extent of badland change over more than sixty years. The current satellite imagery and new terrain data (LiDAR) were further used as a basis to characterize topographic variables of badlands.

The Ugum watershed was selected for this study. The watershed encompasses a 7.3 square miles area located along the eastern coast of Southern Guam (144°42'E, 13°18'N). The study area is a sub-watershed of the Talofofo watershed, the largest drainage system on Southern Guam. The Ugum Watershed includes a 23 miles stream network with two main rivers, the Ugum and Bubulao River. The Bubulao River drains into the Ugum River, which merges into the Talofofo River near the outflow to Talofofo Bay. The elevation of the Ugum Watershed ranges from 20 ft to 374 ft with an overall relief of about 368 354 ft.

The first phase of the project was to quantify the badland changes over a long period of time. An inventory of available aerial and satellite imagery was made to find two suitable images from different years to look for changes in badlands as shown in Table 1. The oldest available panchromatic (black-and-white) aerial image series dates back to 1946, whereas the most recent satellite image was taken by QUICKBIRD satellite in 2006. The first color satellite image was taken by LANDSAT in 1973 with a resolution of ~ 80 m x 80 m. The aerial photos were all evaluated regarding overall clarity, resolution, badland identification, and cloud cover. The 2006 QUICKBIRD and the 1946 Aerial Photo, spanning over a sixty year period, were determined the most suitable.

The image inscribed "GC12B.83-VV-3RS-M-30ENG-1FEB46-MI" (further called "AP46") covering a large part of the Ugum Watershed was chosen for this time-series analysis. Although other images also depict the study area, they only show it on the edge of the photograph where the distortion is the greatest. For this reason, a smaller area within the study area was selected for the time series analysis.

Using the geographic information system (GIS) software ArcGIS 9.1, we rectified the GC12B.83 image three times. Each time we focused the ground control points (GCPs) on different areas of the image to minimize the root mean square error (RSME). The GCPs were derived from the 2006 QUICKBIRD satellite imagery.

Table 1. Inventory of Available Aerial Imagery on Guam.

Name	Year	Area Covered	Date taken	Format	Number of Sheets	Resolution
QUICKBIRD	2006	Whole Island	May 05 - Mar 06	digital		0.6 m x 0.6 m (pan-sharpened)
	2005	Whole Island	Nov 03 - Feb 05	digital		
IKONOS	2004	Whole Island	Nov 02 - Jan 04	digital		4 m x 4 m
Landsat	2000	Whole Island		digital		
	1974	Whole Island		digital		
Aerial Ortho-Photos	1993	Whole Island	1992 - 1994	hardcopy, digital		
Aerial Photos	1986	North	1985 - 1986	hardcopy, scans	55	
	1975	Whole Island	5/30/1975 - 7/8/75	hardcopy, scans	91	
	1974	Whole Island		hardcopy - ca. 22 x 34		
	1973	Agat, Tamuning	24-Aug-73	hardcopy, scans	58	
	1970	Central	4-Jun-70	hardcopy, scans		
	1969	North, Central	26-Jan-69	hardcopy, scans	90	
	1964	Whole Island		hardcopy, scans	115	
	1964	North	30-Mar-64	hardcopy, scans	53	
	1956	Whole Island	12-Mar-56		38	
	1953	Whole Island	26/28-Jan-53	hardcopy, scans	191	
	1946	Whole Island	1-Feb-46	hardcopy, scans	58	600dpi

A third-order polynomial transformation was used for all three versions, with a total RMS Error of 1.85, 1.89, and 1.96 meters, respectively. The images were reassembled to a cell size of one meter using the bilinear interpolation method and saved as IMAGINE image format. The reassembled images were then clipped to their extent of focus and photo-mosaicked to one single file. Figure 1 shows the image of 1946 and 2006 used for this study.

To characterize the physical attribute of the badlands such as elevation, slope, and aspect ratio we used Light Detection and Ranging (LiDAR) data. LiDAR data for Guam was collected for the Government of Guam Department of Public Works and Homeland Security between February and May 2007. At the time of this analysis only draft LiDAR data was available.

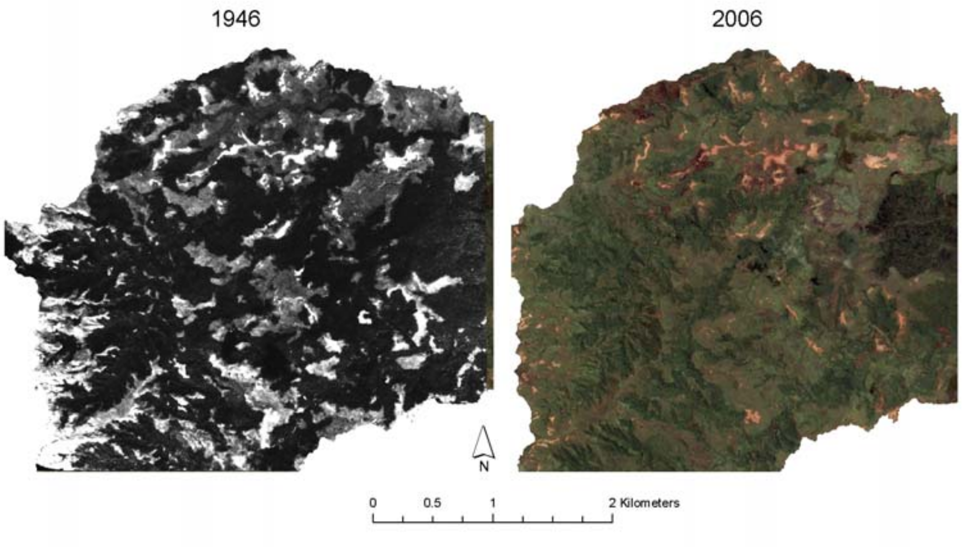

Figure 1. Georeferenced aerial imagery (1946) and QuickBird satellite imagery (2006).

The draft LiDAR data was used to derive watershed boundaries, slope, aspect, and elevation. Because the resolution of the newly available LiDAR data is much greater than the currently used 10-meter-resolution DEM by USGS and, therefore, more subtle changes in the terrain can be detected, the LiDAR dataset was used as a basis for the terrain analysis (elevation, watershed boundaries etc.).

Principal Findings and Significance:

Badland Change: The first finding was badland changes between 1946 and 2006 as shown in Figure 2. Both raster layers (GC12B.83 and QB46) were evaluated together using the mathematical function *Addition* in the Raster Calculator: "AP46 + QB06". The outcome as shown in Table 2 and 3, reveals that the areas that have not been badland in either years; badland in 1946, but not in 2006, not badland in 1946, but in 2006, badland in both years.

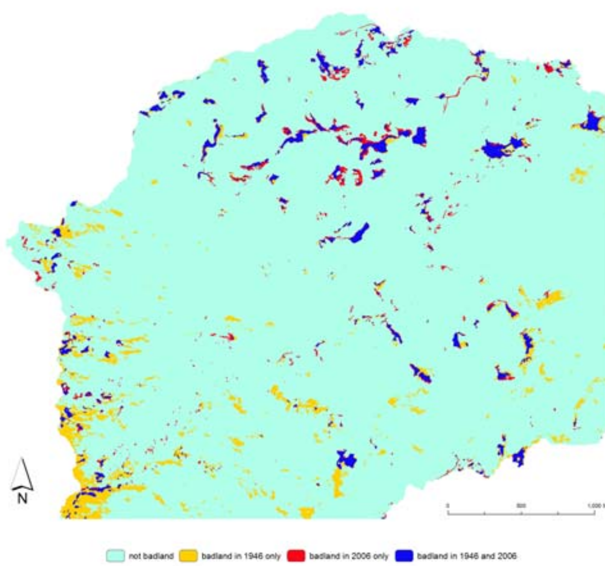

Figure 2. Geo-referenced aerial imagery (1946) and QuickBird satellite imagery (2006) of study area.

Table 2: Statistical Breakdown (in ha and %) of Areas that were not Badlands in 1946 & 2006, Badland in 1946 only, Badland in 2006 only, and Badland in 1946 & 2006.

Type	M2	%
Not badland in 1946 or 2006	1025.28	92.72
Badland only in 1946	42.85*	3.88*
Badland only in 2006	14.67	1.32
Badland in 1946 & 2006	22.98	2.08
Total Study Area	1105.78	100

* erroneous due to misclassification

Table 3: Total area (in ha and %) of Badlands and Other Land Cover in 1946 & 2006.

	Badland		Other Land Cover		Total Area (ha)
	ha	%	ha	%	
1946	65.82*	5.95*	1039.96	94.05	1105.78
2006	37.65	3.40	1068.13	96.60	1105.78
Change	-28.17*	-2.55*	28.17	2.55	-

* erroneous due to misclassification

A structural pattern analysis revealing the number, size, and distance to closest neighbor was performed using the Vector-based Analysis Tools Extension V-LATE developed by the Landscape and Resource Management Research Group (LARG 2005). We used images of 2006 for this analysis as shown in Table 4.

Table 4: Structural Pattern Characteristics of Badland Patches in 2006, Ugum Watershed, Guam.

Year	Number of patches	Mean	SD	Min	Max	Sum
Area (m^2)	819	673.8	1832.3	5.6	25042.9	553849.7 (55.39 ha)
Perimeter (m)		129.4	195.7	8.8	2103.6	105981.8 (106.00 km)
Distance to NN (m)		20.1	28.8	0	246.5	-

Terrain Attributes: The second finding was relationship between badland occurrence and terrain attributes, such as elevation above mean sea level, slope, and aspect, but also other factors like geology and soils was also considered and analyzed in order to assess their influence on the badlands. The Spatial Analysis Tool *Zonal Statistics* was used for this analysis. The geology (Tracey *et al.* 1964) and soil layer (based on Young 1985) were downloaded from the Natural Resources Atlas of Southern Guam website (WERI & IREI 2008). The results are shown in Tables 5, 6, 7, and Figures 3 and 4.

Table 5: Elevation Distribution of Badlands (BL) and the Entire Ugum Watershed and their Proportional Abundance.

ELEVATION (m)		< 50	50 - 100	100 - 150	150 - 200	200 - 250	250 - 300	300 - 350	> 350	SUM
Area (ha) (Proportion of total Area)	Ugum	134.6 (7.32%)	516.5 (28.1%)	708.7 (38.5%)	227.3 (12.3%)	109.4 (5.95%)	72.6 (3.94%)	55.4 (3.01%)	13.1 (0.71%)	1837.6 (100%)
	BL	0.3 (0.50%)	11.2 (20.3%)	31.1 (56.3%)	4.4 (7.89%)	0.6 (1.06%)	2.1 (3.78%)	4.7 (8.58%)	0.8 (1.46%)	55.2 (100%)
% BL per Category*		**0.21**	2.17	4.39	1.92	0.54	2.88	**8.57**	**6.15**	N/A
% BL in Ugum**		0.02	0.61	**1.69**	0.24	0.03	0.11	0.26	0.04	3.01

* Proportional Abundance of Badlands per Elevation Category

** Badland Cover in Ugum

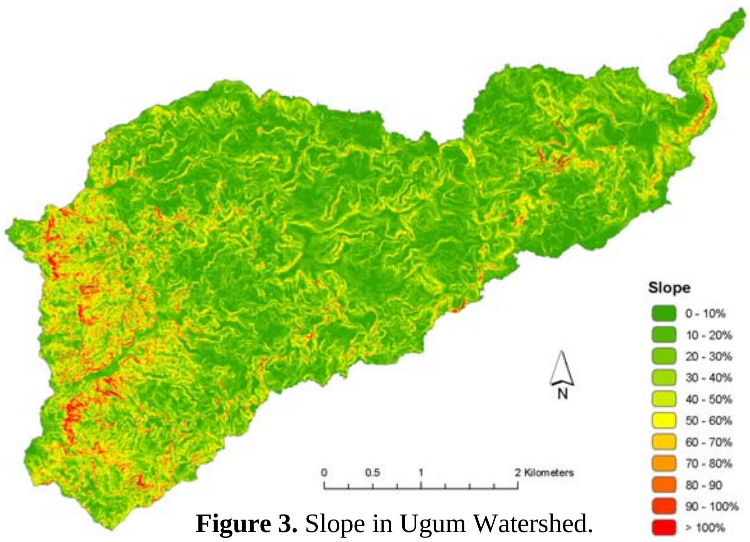

Figure 3. Slope in Ugum Watershed.

Table 6: Slope Distribution of Badlands and the Entire Ugum Watershed and Their Proportional Abundance.

SLOPE (%)		0 - 10	10 - 20	20 - 30	30 - 40	40 - 50	50 - 60	60 - 70	70 - 80	80 - 90	90 - 100	> 100	SUM
Area (ha) (% of total Area)	Ugum	386.2 (21.03%)	497.5 (27.09%)	335.0 (18.24%)	221.4 (12.05%)	149.0 (8.11%)	100.3 (5.46%)	66.9 (3.64%)	41.0 (2.23%)	22.1 (1.20%)	10.6 (0.58%)	6.8 (0.37%)	1836.8 (100)
	BL	10.0 (18.03%)	17.0 (30.67%)	11.7 (21.17%)	7.2 (13.00%)	4.3 (7.81%)	2.4 (4.38%)	1.3 (2.38%	0.8 (1.41%)	0.4 (0.70%)	0.2 (0.33%)	0.1 (0.13%)	55.3 (100%)
% BL per Category*		2.58	3.41	**3.49**	3.25	2.90	2.41	1.97	1.90	1.76	1.69	**1.07**	N/A
% BL in Ugum**		0.54	**0.92**	0.64	0.39	0.23	0.13	0.07	0.04	0.02	0.01	**< 0.01**	3.01

Frequency distribution of slope *Percent cover of badlands per slope category*

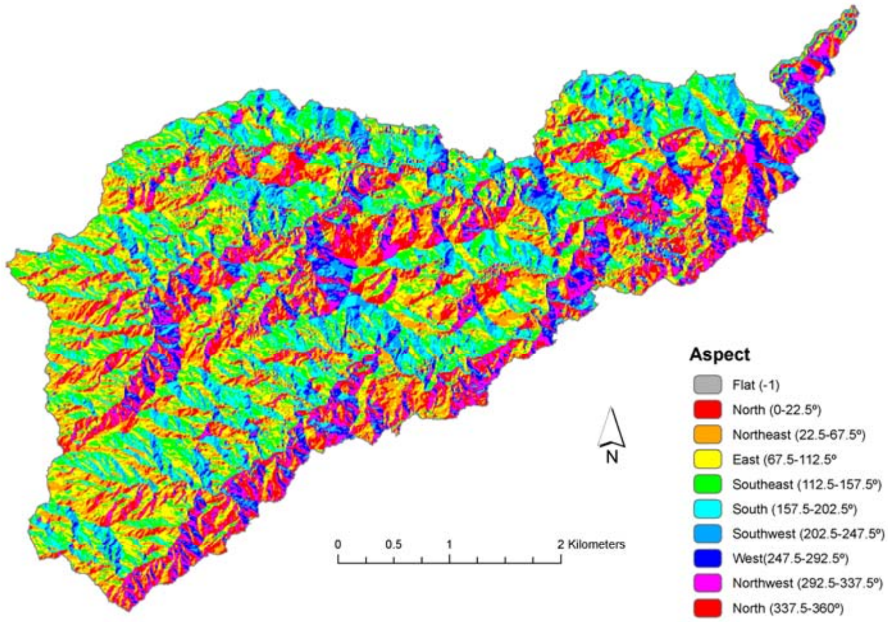

Figure 4. Aspect in Ugum Watershed.

Table 7. Aspect Distribution of Badlands and the Entire Ugum Watershed and Their Proportional Abundance.

ASPECT		N 337.5º - 22.5º	NE 22.5º - 67.5º	E 67.5º - 112.5º	SE 112.5º - 157.5º	S 157.5º - 202.5º	SW 202.5º - 247.5º	W 247.5º - 292.5º	NW 292.5º - 337.5º	SUM
Area (ha) (Proportion of total Area)	Ugum	254.4 (13.9%)	287.9 (15.7%)	295.8 (16.1%)	296.5 (16.1%)	230.8 (12.6%)	150.8 (8.2%)	134.7 (7.3%)	186.8 (10.2%)	1837.6 (100%)
	BL	5.8 (10.5%)	8.2 (14.8%)	9.9 (17.8%)	11.4 (20.6%)	8.2 (14.9%)	4.0 (7.3%)	3.6 (6.5%)	4.2 (7.6%)	55.2 (100%)
% BL per Category*		2.28	2.85	3.33	**3.83**	3.56	2.67	2.64	**2.26**	N/A
% BL in Ugum**		0.32	0.45	0.54	**0.62**	0.45	0.22	**0.19**	0.23	3.01

We analyzed the extent of badlands in 1946 and 2006 in a small study area within the Ugum Watershed. Our results show that badlands are dynamic. Almost 40 percent of today's badlands have developed over the last 60 years. Some badlands also disappeared, but the exact number could not be determined because of problems in the classification process.

We also examined the effect of topography on badland occurrence in the Ugum Watershed. Our results suggest a significant relationship of badland occurrence with elevation, slope, distance to drainage divide, and soil, but not with geology or aspect. The conclusions drawn here need to be confirmed for other areas in southern Guam so that results can be used more reliable to model potential badland areas.

This study provided valuable reconnaissance information regarding badland changes over time. However, we were only able to look the extent of badlands in two years (1946 and 2006). A more extent and finer time-scale will produce more evidence on the rate of change as well as inter-decadal variances.

Re-vegetation is an important measure to stop or at least slow erosion processes. By identifying younger badlands in our study, future research could use this information to test whether younger badlands have a better ability to be re-vegetated because they might not have fully eroded to the bedrock. Understanding more about badland behavior is essential to better manage them. Therefore, more research needs to be directed toward these highly erodible surfaces.

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